2

SECONDARY POWER SYSTEMS

PRODUCTION BASE ANALYSIS STUDY

GENERAL RESEARCH CORPORATION
DAYTON TECHNICAL OFFICE
Wright Executive Center, Suite No. 390
2940 Presidential Drive, Fairborn, OH 45324-6223
A SUBSIDIARY OF FLOW GENERAL INC.

JULY 1988

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS: N/A
2a. SECURITY CLASSIFICATION AUTHORITY: N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT: Unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): N/A	5. MONITORING ORGANIZATION REPORT NUMBER(S): N/A
6a. NAME OF PERFORMING ORGANIZATION: General Research Corp; 6b. OFFICE SYMBOL (If applicable): N/A	7a. NAME OF MONITORING ORGANIZATION: HQ AFSC/PLMI
6c. ADDRESS (City, State, and ZIP Code): 2940 Presidential Drive, Wright Executive Center, Suite 390, Fairborn, OH 45324-6223	7b. ADDRESS (City, State, and ZIP Code): Wright-Patterson AFB, OH 45433-6503
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Aerospace Industrial Modernization Office; 8b. OFFICE SYMBOL (If applicable): HQ AFSC/PLMI	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F33657-85-D-2191
8c. ADDRESS (City, State, and ZIP Code): Same as Block 7b.	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
PE78011F	N/A	013	N/A

11. TITLE (Include Security Classification): Secondary Power Systems (SPS) Production Base Analysis (PBA) Study /Unclassified

12. PERSONAL AUTHOR(S): Dickson, David S.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Jan 87 TO Jul 88	July 1988	60

16. SUPPLEMENTARY NOTATION: N/A

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Industrial Base Planning, Secondary Power Systems, Auxillary Power Systems, MANTECH, IMIP, Industrial Preparedness Measure (IPM), Turbine Technology.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The study focused on the technical characteristics of propulsion Gas Turbine Engines (GTEs) and the power system GTEs and how these characteristics have influenced U.S. producers. Two general GTE industrial sectors were identified, large GTEs and small GTEs. Large GTEs are used for propulsion of military/civil aircraft and military seacraft; power generation for military seacraft; and, civil stationary power plants. Small GTEs are used for propulsion of military missiles and drones, military/civil helicopters and military/civil landcraft; power generation for military/civil aircraft/helicopters; and, mobile ground power units. Two aspects of the sector of power generation for military/civil aircraft/helicopters, referred to as secondary power systems (SPS), on which this study focused.

(1) The evolving common technology needs which would secure the U.S. world market dominance well into the 21st century.

(cont'd on reverse)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Robert L. Rice	22b. TELEPHONE (Include Area Code): (513) 255-3920; 22c. OFFICE SYMBOL: HQ AFSC/PLMIP

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

BLOCK 19 (Continued):

(2) The interrelated nature of the industrial base supporting prime SPS producers and other subsystems.

Operational requirements of modern day aircraft have expanded greatly from past aircraft needs. Future military SPS operational requirements dictate highly ambitious technology goals for the year 2000. The large GTE life cycle activities are undergirded by a continuum of technological activity that is both well funded and managed by the DOD. The Air Force technology goals established for SPS for the year 2000 are extremely ambitious in comparison to historical accomplishments.

Historically, SPS have received intermittent, selective government support and has made much less technological progress than the large GTE. In addition, market pressures dictate lower costs and higher reliability and maintainability. These factors combine to suggest the need for significant advances in materials and manufacturing processes to be used in sps; advances in such areas as materials and processes which have not been perfected for use in production.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

E.1 BACKGROUND

This study of the Secondary Power System (SPS) sector of the US Defense Industrial Base was performed in response to both Department of Defense (DOD) directive as well as the findings from previous Production Base Analysis (PBA) studies. DOD Instruction 4005.3, "Industrial Preparedness Program Planning" requires the services, in conjunction with private industry and other federal agencies, to conduct industrial preparedness planning of resources to ensure ready and controlled sources of technical competence to support the modernization, readiness and sustainability of combat forces.

E.2 OBJECTIVE

Initially it seemed advisable to embark upon an in-depth review of the SPS sector as recommended by the Gas Turbine Engine (GTE) PBA Study Final Report. Study methodology of a parallel nature to that used for the GTE PBA Study would be applied to assess the SPS Primes and the critical subcontractors. A subsequent shift of emphasis resulted in a reorganization of the study task objectives as follows:

(1) Study the aircraft secondary power system industrial base to obtain a better definition of: a) the industrial base to which it belongs; and b) the industrial bases to which it is closely related and/or dependent.

(2) Assess the current technological strength of the aircraft SPS industrial base and identify future steps to maintain a healthy industrial base.

E.3 STUDY APPROACH

A top down view of the world wide SPS industrial base was taken to identify the various SPS markets in which the U.S. producers are active and what portion of the world SPS market is currently held by these producers.

From this point on, the study focused on the related technical characteristics between propulsion GTEs and the power system GTEs and how these characteristics had influenced the U.S. GTE producers. From this effort it became apparent that two general

GTE industrial sectors could be identified each involving similar GTE propulsion and power applications. These applications were defined as large GTEs and small GTEs. Large GTEs are used for propulsion of military/civil aircraft and military seacraft; power generation for military seacraft; and, civil stationary power plants. Small GTEs are used for propulsion of military missiles and drones, military/civil helicopters and military/civil landcraft; power generation for military/civil aircraft/helicopters; and, mobile ground power units.

At this point, the study focused on two aspects of the small GTE industrial base:

(1) The evolving common technology needs for propulsion and power GTEs which, if satisfied, could secure the U.S. world market dominance well into the 21st century.

(2) The interrelated nature of the industrial base supporting the prime SPS producers to the other industrial bases supporting production of electrical/hydraulic subsystems, environmental control subsystems, propulsion start subsystems and a variety of mobile ground power supply carts/sets.

E.4 STUDY FINDINGS

- The majority of military SPS applications are produced by these same two Primes.
- Single source SPS suppliers are common to GTE critical suppliers.
- Critical SPS occupations are those requiring excessive training times.
- Foreign source dependencies exist for specialized manufacturing equipment.
- SPS gas generator production is dependent upon availability of several strategic and critical materials for high temperature alloys.
- Airborne SPS equipment, with the APU being the core of the entire system, is unique due to its operation, size and duty cycle.
- The duty cycles imposed on APUs are more severe than those imposed on the main engine consisting of severe

mechanical and thermal transients, efficient operation over a wide speed range, high mission operation mix, with high reliability and ease of maintenance.

- Modern day aircraft have operational requirements which have expanded greatly over past aircraft needs.

- Future military SPS operational requirements have led to highly ambitious technology goals for the year 2000.

- The large GTE life cycle activities are undergirded by a continuum of technological activity that is both well funded and managed by the DOD.

- The Air Force technology goals established for SPSs for the year 2000 are extremely ambitious in comparison to historical trends.

- The physical size of APU components required for modern-day and future tactical aircraft have imposed limits on technology transfer from large gas turbine engines. For instance, the cooling air passages in the turbine blades of a 30,000 pound thrust turbofan engine are significantly larger than the entire blade tip for a 500 horsepower APU.

- Even for the modern-day, first line aircraft, SPS requirements are typically not defined until late in the FSED phase of the acquisition cycle. This lack of consideration during the conceptual design usually results in the SPS being limited to state-of-the-art technology.

E.5 STUDY CONCLUSIONS

- Without major across-the-board technological breakthroughs future systems will continue to suffer SPS performance shortfalls.

- Future demands of the SPS require designs which are smaller, lighter and more powerful than today's units. In addition, market pressures dictate lower costs and higher reliability and maintainability. These factors combine to suggest the need for significant advances in materials and manufacturing processes to be used in SPSs; advances in such areas as materials and processes which have not been perfected for use in production.

- Increased demands can no longer be satisfied by increases in component efficiency and capability. Integrated designs must be developed, and demonstrated to achieve projected goals.

- Fragmented, multi-agency SPS development activities will not meet projected requirements. Only through a well-managed technology program will the projected military SPS weapon system operational requirements be met.

E.6 STUDY RECOMMENDATIONS

- Identify and document the specific SPS technologies (materials, components, gas generator, SPSs) that must be achieved to meet the projected weapon system operational requirements.

- Conduct a more detailed review of the SPS subcontractor base to identify critical material and component suppliers to the production of secondary power systems for future weapon system acquisitions.

SECONDARY POWER SYSTEMS

1.0 INTRODUCTION

1.1 BACKGROUND

This study of the Secondary Power System (SPS) sector of the US Defense Industrial Base was performed in response to findings from the Gas Turbine Engine (GTE) Production Base Analysis (PBA) Study. DOD Instruction 4005.3, "Industrial Preparedness Program Planning" requires the services, in conjunction with private industry and other federal agencies, to conduct industrial preparedness planning of resources to ensure ready and controlled sources of technical competence to support the modernization, readiness and sustainability of combat forces. The study concentrated on SPSs because they are a major long leadtime component of systems on the Air Force (AF) Critical Items List (CIL).

A top down view of the world wide SPS industrial base was taken to identify the various SPS markets in which the U.S. producers are active and what portion of the world SPS market is currently held by these producers. The study then focused on the related technical characteristics between propulsion GTEs and the power system GTEs and how these characteristics had influenced the U.S. GTE producers. From this effort it became apparent that two general GTE industrial sectors could be identified each involving similar GTE propulsion and power applications. These applications were defined as large GTEs and small GTEs. Large GTEs are used for propulsion of military/civil aircraft and military seacraft; power generation for military seacraft; and, civil stationary power plants. Small GTEs are used for propulsion of military missiles and drones, military/civil helicopters and military/civil landcraft; power generation for military/civil aircraft/helicopters; and, mobile ground power units. For convenience, the whole gamut of SPSs (auxiliary power units (APUs), jet fuel starters (JFSs), etc.,) was included in the general category of small GTEs.

In the early 1960s there were several sources for SPSs. These systems are more generally called turbomachinery or power system GTEs. These sources were Thompson Products, Boeing, Pratt & Whitney, Marquardt, Solar, Sundstrand, Hydroaire, Bendix, Garrett, Lycoming, Teledyne, General Electric, Williams, and Allison. They were aggressively pursuing development and production of power system GTEs. Today this industry segment has been markedly reduced. There are currently two (2) companies in the United States that support SPS development and production with one (1) additional source in Canada. The US firms are Garrett

and Sundstrand Turbomach. Solar and Bendix still retain a very small portion of this business base. Pratt & Whitney, Canada is the other resource outside the US, and is part of the North American Defense Industrial Base (NADIB).

1.2 STUDY ORGANIZATION

1.2.1 Objective

The basic study objective was to identify the companies which comprise this industry sector and characterize that business base, both commercial and military. Additionally, the study was to identify those SPSs which are supported, both in current inventories and those projected to be in the inventory in the next decade.

As the study evolved, the development and application of SPS technology surfaced as a major problem area. In view of the importance of this critical subsystem to future weapon systems operation, characterization of the SPS technology base became a study objective.

1.2.2 Methodology

The general approach to accomplishing the SPS PBA Study was patterned on the GTE PBA Study. Data were gathered via a questionnaire (Appendix A) and interviews with government and industry personnel. These data were supplemented by information found in company documents and the Aeronautical Systems Division (ASD) Technical Library.

The Aerospace Industrial Modernization (AIM) Office, HQ AFSC/PLMI, has overall management responsibility for this study and coordinated the review process for the final report. Comments solicited from participating contractor organizations, AFWAL laboratory personnel and members of the ASD technical staff were incorporated in this report.

2.0 CHARACTERIZATION

2.1 GENERAL DESCRIPTION

2.1.1 Producers

Figure 2-1 shows how the US SPS industry has evolved over the last 35 years. During this time, the industry has dramatically changed in make-up, evolving from 14 narrow-based, product-line producers to the two current broadly based, SPS producers.

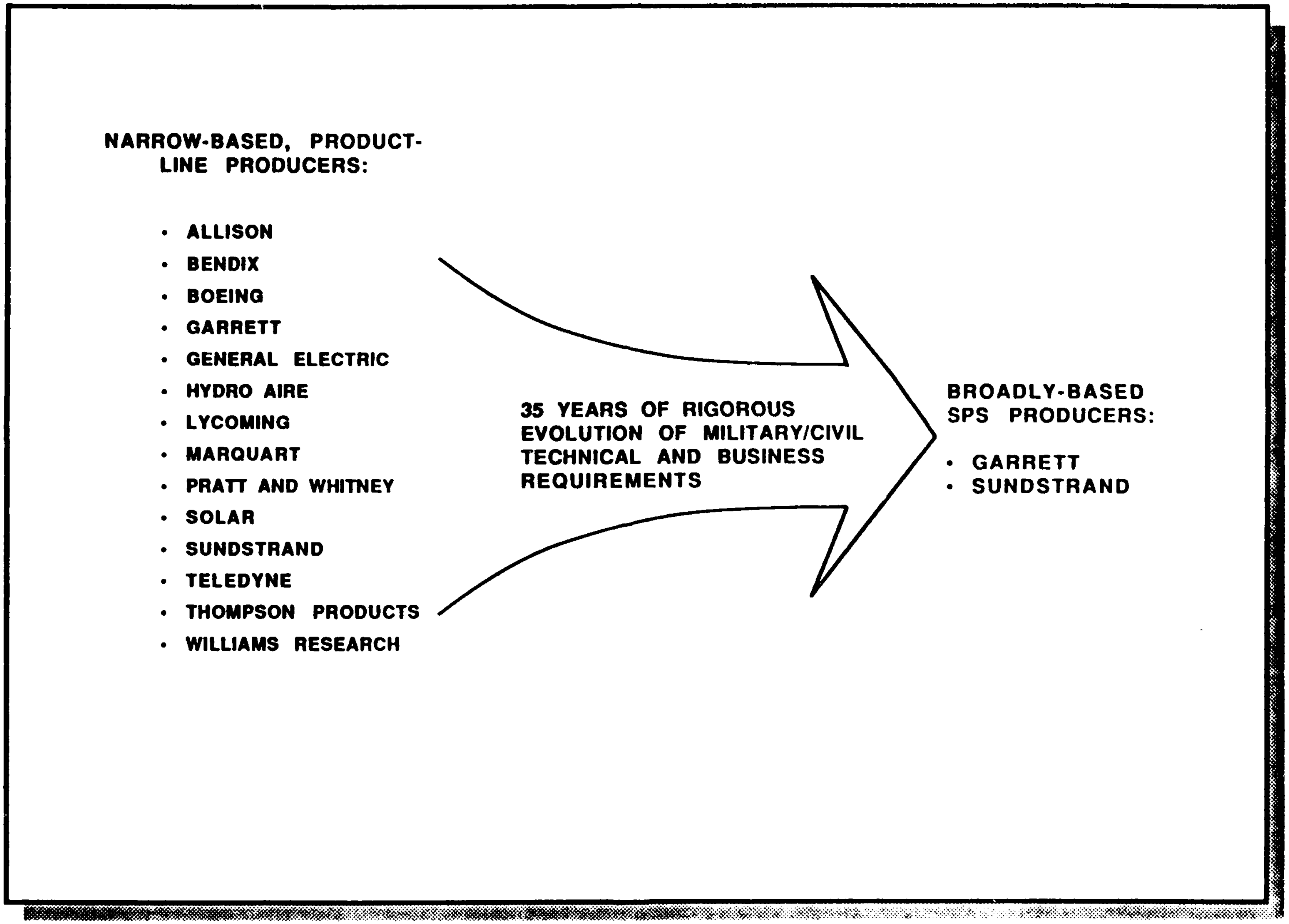


Figure 2-1 THE EVOLUTION OF THE SECONDARY POWER SYSTEM (SPS) INDUSTRY

Garrett Airesearch pioneered the development of the gas turbine auxillary power unit (APU) in the 1940s and early 1950s for use in military aircraft. In the late 1950s and early 1960s, Garrett introduced the gas turbine in commercial aircraft, and to date the company has produced in excess of 50,000 units, which represents nine variants of their basic power system. The only other company to significantly penetrate the SPS market has been Sundstrand Turbomach with essentially one basic power unit, the Titan T-62, which has been built in quantities approaching 12,000, mainly for US military helicopters, fighters and corporate jets.

2.2 PRODUCTS AND APPLICATIONS

2.2.1 General Applications

The APU and Jet Fuel Starter (JFS), which are each small gas turbine engines, are only a portion of the aircraft SPS equipment. In recent years, as SPS requirements have grown larger in numbers and more demanding in terms of power levels and types, the associated equipments have gotten more and more diversified. Figure 2-2 shows some of the aircraft subsystems with which SPS units interface. Each of these subsystems has its own set of requirements which collectively form the general set of SPS application requirements outlined below in Table 2-1.

TABLE 2-1

GENERAL SPS APPLICATION REQUIREMENTS

- Self-sufficient, automatic operation, self diagnostic
- Operation over wide temperature/pressure envelope
- Small volume, light weight
- Fuel efficient over wide load spectrum
- Low life cycle cost

The auxiliary component configuration make-up of the SPS is very sensitive to the aircraft configuration, so numerous packaging arrangements have evolved and are continuing to evolve. Thus, the exact composition of the SPS components varies with the aircraft type. The resulting SPS has a very technically sophisticated set of electrical, hydraulic, pneumatic and hydromechanical interfaces with the aircraft flight and ground support equipment.

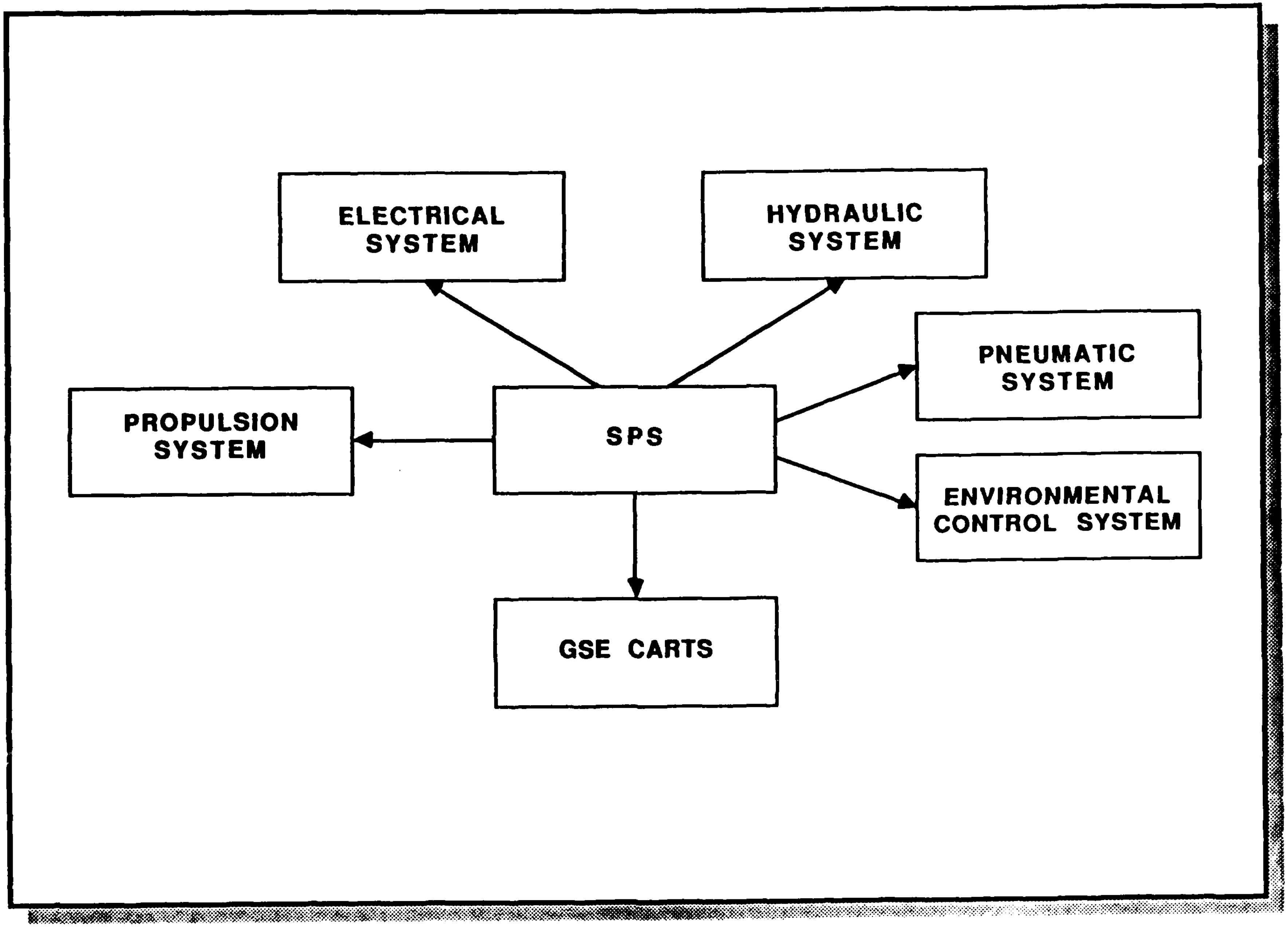


Figure 2-2 AIRCRAFT SECONDARY POWER SYSTEM (SPS) INTERFACES

Each SPS has a core gas generator comprised of a compressor, a combustor and a turbine. Other turbomachinery, gear boxes, controls, heat exchangers, inlets and nozzles are added to satisfy the peculiar requirements of the propulsion or power system application.

Propulsion GTEs are classified into one of four categories: turboprop, turboshaft, turbojet and turbofan. Although all four categories were initially developed by the DOD for airborne military systems, propulsion derivatives of all four categories have found their way into military seacraft and civil marine craft. Propulsion derivatives of the turboshaft engine have found limited applications for military land vehicles and civil railcraft. In addition, the larger propulsion GTEs have found a broad market for power generation derivatives for civil stationary power generation units.

Secondary power systems are not as easily classified, as no simple, universal identification system has been adopted. Table 2-2 identifies three broad classifications that are used according to the power system requirements for the SPS.

TABLE 2-2

POWER SYSTEM SPS CLASSIFICATION

- Pneumatic power provided by an integral bleed APU or direct driven air compressor.
- All shaft power secondary power units (SPU) driving into a light weight gearbox which drives hydraulic pumps, electrical generators, system controls and accessories, and a gearbox driven load compressor for environmental control system (ECS) air supply and main engine starting. For aircraft mounted systems a mechanical link can be provided for self sufficient main engine starting and limited motoring of the main engine and its accessories.
- A combination of pneumatic and shaft power.

Although some of the secondary power systems were initially developed for military fixed wing aircraft and helicopter applications, derivative designs quickly found broad application in military/civil mobile power carts and military mobile power generation sets. To date, limited power generation applications have occurred for a variety of military land vehicles. Figure 2-3 depicts the data on world-wide applications of power systems. It can readily be seen that US producers dominate this market.

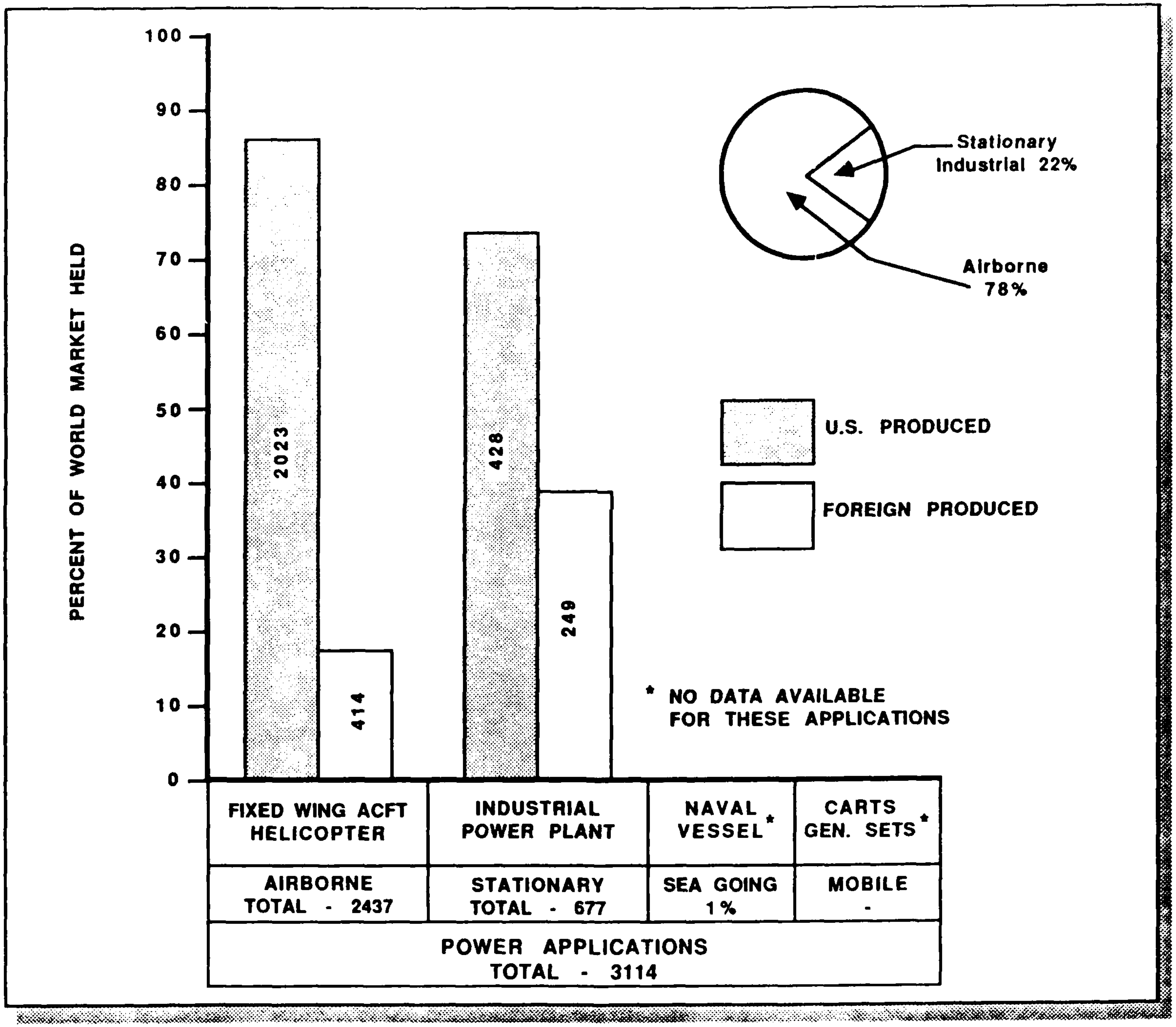


Figure 2-3 GTE POWER APPLICATIONS

2.2.2 Military Applications

SPS application to military weapon systems involves ground and in-flight power to: start main engines; drive electrical generators and hydraulic pumps; and, provide pneumatic power for aircraft heating and cooling systems. Weapon system SPS applications identified during the course of this study include the following categories:

1. Auxillary Power Unit (APU) - A small air breathing gas turbine engine which provides shaft horsepower to generate electrical and hydraulic power as well as pressurized air for ground cooling and engine starting.

2. Jet Fuel Starter (JFS) - A small gas turbine engine which is mechanically connected to the propulsion engine to provide power for starting.

3. Air Turbine Starter (ATS) - An air turbine which is mechanically connected to the main propulsion syustem for starting. A source of pressurized air must be provided to power the turbine.

4. RAM Air Turbine (RAT) - An emergency device consisting of an impeller which can be moved out into the airstream to provide emergency power.

5. Emergency Power Unit (EPU) - A non air breathing turbine power unit capable of very quick starts at any altitude or airspeed to provide relatively small amounts of shaft power to provide emergency electrical and hydraulic power. The F-16 is the only production aircraft that has an EPU installed.

A tabulation of the SPS units currently installed on existing DOD weapon systems is shown in Table 2-3.

TABLE 2-3

SECONDARY POWER SYSTEM EQUIPMENT

SYSTEM	EQUIPMENT	ENGINE T/M/S	MANUFACTURER
A-4	JFS	JFS-100-34	Garrett
A-6	APU, ATS	GTCP 36-201	Garrett
A-7	JFS	JFS-100-13A	Garrett
A-10	APU	GTCP 36-50	Garrett
AH-64	APU	GTCP 36-55	Garrett
B-1B	APU, ATS	GTCP 165-7A/9A	Garrett
C-5	APU, ATS, RAT	GTCP 165-1	Garrett
C-9	APU	GTCP 85-98D	Garrett
C-17	APU	GTCP 331-200	Garrett
C-130	APU, ATS	GTC/GTCP85	Garrett
CH-47	APU	T62-T2	Sundstrand Turbomach
CH-53	APU	T62-T12/27	Sundstrand Turbomach
E-3	APU	GTCP 165-1	Garrett
E-4	APU	GTCP 660-4	Garrett
E-6	APU	GTCP 165-1	Garrett
F-15	JFS	JFS-190-1	Garrett
F-16	JFS	T62-T40-8	Sundstrand Turbomach
KC-10	APU, ATS	TSCP 700-4/4B	Garrett
KC-135R	APU	T62-T40LC-2	Sundstrand Turbomach
T-43	APU	GTCP 85-129	Garrett
UH-60	APU	T62-T40-1	Sundstrand Turbomach
V-22	APU	T62-T46	Sundstrand Turbomach

Compared to civil applications, military SPSs place more stringent demands on the application of state-of-the-art technology. Historically, weight and volume "bogeys" are allocated for SPS subsystems as part of the design process. As the system approaches full scale engineering development and the true requirements become better defined, the combination of subsystem weight and cost "growth" invariably surfaces. These historical system development realities, combined with operational Air Force pressures to achieve better combat readiness and capability figures, drive SPS technology application to the limit. Table 2-4 identifies the major criteria facing the designer of military application SPS units.

TABLE 2-4

MILITARY SPS DESIGN CRITERIA
• Higher power density • Improved reliability and maintainability (R&M) goals • Improved specific fuel consumption • Lower life cycle cost objectives • Reduced acquisition cost through improved manufacturing and producibility.

2.3 FINANCIAL

Over 90 percent of the SPS sales (shipments) in the US are provided by the two producers, Garrett and Sundstrand Turbomach. For 1986, total shipments (defense and non-defense) were in excess of $1 billion. Of this total dollar value, approximately 44 percent of the shipments were defense related.

In this same year, these two producers invested in excess of $30 million in facilities, machinery and equipment associated with SPS production. Investments in R&D for 1986 were somewhat smaller (less than $10 million) and were predominantly company sponsored (Independent Research and Development (IR&D)). This equates to less than one percent of sales, whereas the aerospace industry on the average spends about 15 percent of gross sales for R&D. The Government sponsored portion of the R&D expenditures was identified at approximately two percent.

2.4 MANUFACTURING CONCERNS

One of the main objectives in Industrial Base Planning is understanding the constraints to peacetime production. The need for AFSC to provide a quality product to the user is paramount. The development and acquisition community must continually strive to increase quality and reliability and make the product easier to maintain. Some of the major industrial base planning concerns identified in the manufacture of SPS are detailed below.

Sole/Single Source: Numerous SPS components are produced by single source suppliers. In many instances, these suppliers were the same suppliers who were providing critical components or materials for the production of propulsion GTEs as identified by the GTE PBA Study. This situation was particularly true for castings suppliers. Alternate sources are pursued where it is cost effective and feasible.

Foreign Sources: No critical SPS components were identified as being procured from foreign sources. However, several pieces of manufacturing equipment were foreign sourced, but only one (5 axis mill) was documented as being available only from that foreign source. (Note: 5-axis machines can be obtained from domestic sources) No specific contingency plans exist to qualify domestic sources for the foreign sourced manufacturing equipment.

Critical Occupations: These occupations are defined as those for which labor shortages would be anticipated during a surge or mobilization, or where normal training times were greater than 12 months. Experienced engineers, including design, manufacturing, instrumentation and logistics support disciplines were listed. In addition, skilled machinists and technicians for specialized equipment operation and maintenance were identified. In every case, the principal requirement was the extensive training required to achieve minimum skill levels. Training periods ranged from high school plus three to seven years, to college plus three to seven years experience.

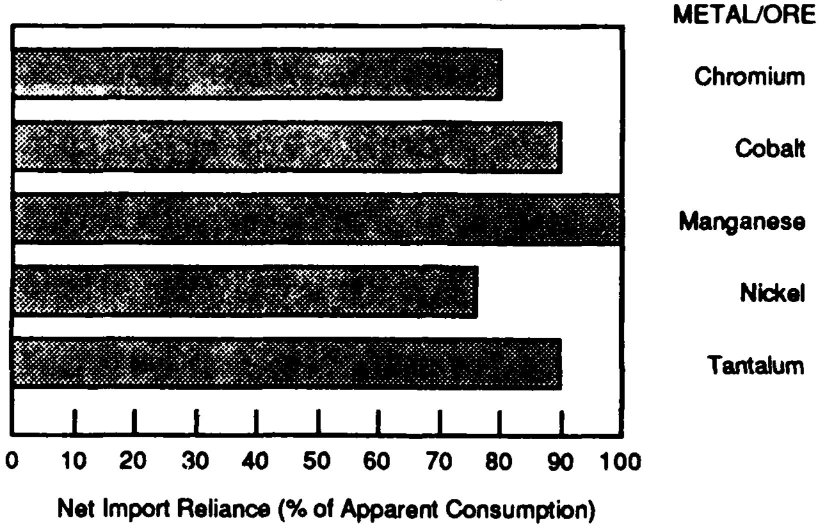
Strategic and Critical Materials: The gas generator core portion of the SPS utilizes many strategic and critical materials. Table 2-5 lists the materials that were identified by both Primes as essential for SPS production. These materials are required in the production of high temperature alloys and are available only from foreign sources. The US is greater than 78 percent reliant on foreign sources for these materials. During times of increased tensions or hostilities these sources would be suspect due to socio-political considerations. A final observation on these critical materials concerns the Defense stockpile for these materials. Nickel currently has 20 percent of the stockpile goal on hand; however, none of it is in a useable form for propulsion or power systems GTE applications. Similar trends are shown for chromium, cobalt, manganese and tantalum.

TABLE 2-5

SPS STRATEGIC/CRITICAL MATERIALS USAGE

CHROMIUM COBALT	TANTALUM	NICKEL MANGANESE

FOREIGN DEPENDENCY



MAJOR FOREIGN SOURCES

So. Africa, Zimbabwe, Turkey, Yugo.

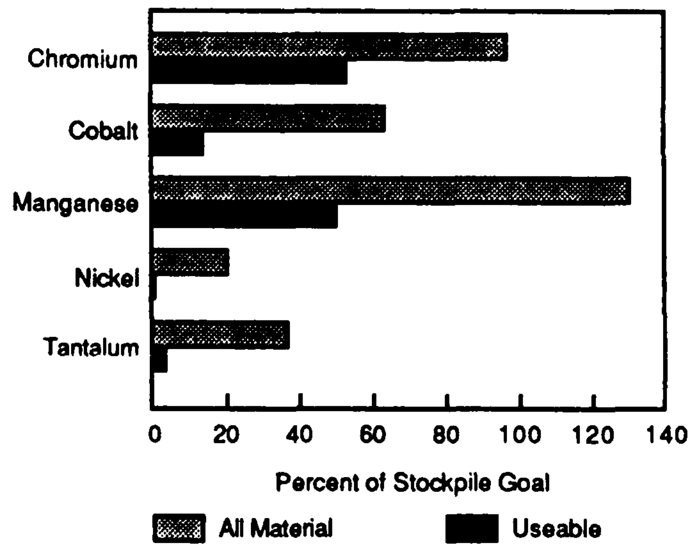
Zaire, Zambia, Canada, Norway

Brazil, Gabon, France, So. Africa

Canada, Australia, Norway, Botswana

Thailand, Brazil, Australia, Malaysia

STOCKPILE ASSETS



3.0 SECONDARY POWER SYSTEMS TECHNOLOGY

3.1 OPERATIONAL REQUIREMENTS

One of the first APUs built for military applications consisted of a small gas turbine engine coupled to an electric generator on board a Lockheed C-130 transport aircraft. SPSs have increased in size, power and numbers of applications. Advanced tactical aircraft have operational requirements, as reflected in Table 3-1, which have expanded greatly beyond past needs.

TABLE 3-1

SPS OPERATIONAL REQUIREMENTS

- Independence from ground support equipment
- Minimum operation on propulsion GTEs
- Reduced overall power system size and weight
- Propulsion GTE accessory system operational capability

Today, SPS requirements typically do not get defined until late in the full scale engineering development (FSED) phase of the weapon system. This lack of consideration during the early design stages results in the SPS being limited to what is currently available within the size and power requirements needed by the weapon system Prime. Airborne SPS equipment, with the APU being the core of the entire system, is unique due to its operation, size and duty cycle. The duty cycles imposed on APUs are quite severe since the APU cold soaks at altitude to a low temperature from which it must often start and achieve full power shortly after returning to the ground. By contrast, the main engine starts at ground ambient and remains thermally stable (relatively) during the flight.

The physical size of APU components required for modern-day and future tactical aircraft has imposed limits on technology transfer from large propulsion GTEs. For instance, the cooling air passages in the turbine blades of a 30,000 pound thrust turbofan engine are considerably larger than the tip of the turbine blade from a 400 horsepower APU. Figure 3-1 shows the cross-section of a 400 horsepower APU turbine blade in the lower left-hand corner. In the upper right-hand corner of the figure is a cross-section of the turbine blade for the 30,000 pound thrust turbofan engine. The cooling passages which are drilled into this blade would consume the entire blade from the 400 horsepower APU. Cooling schemes are not directly transferable from the propulsion GTEs to the small SPSs; therefore, technology

PBA011588-11

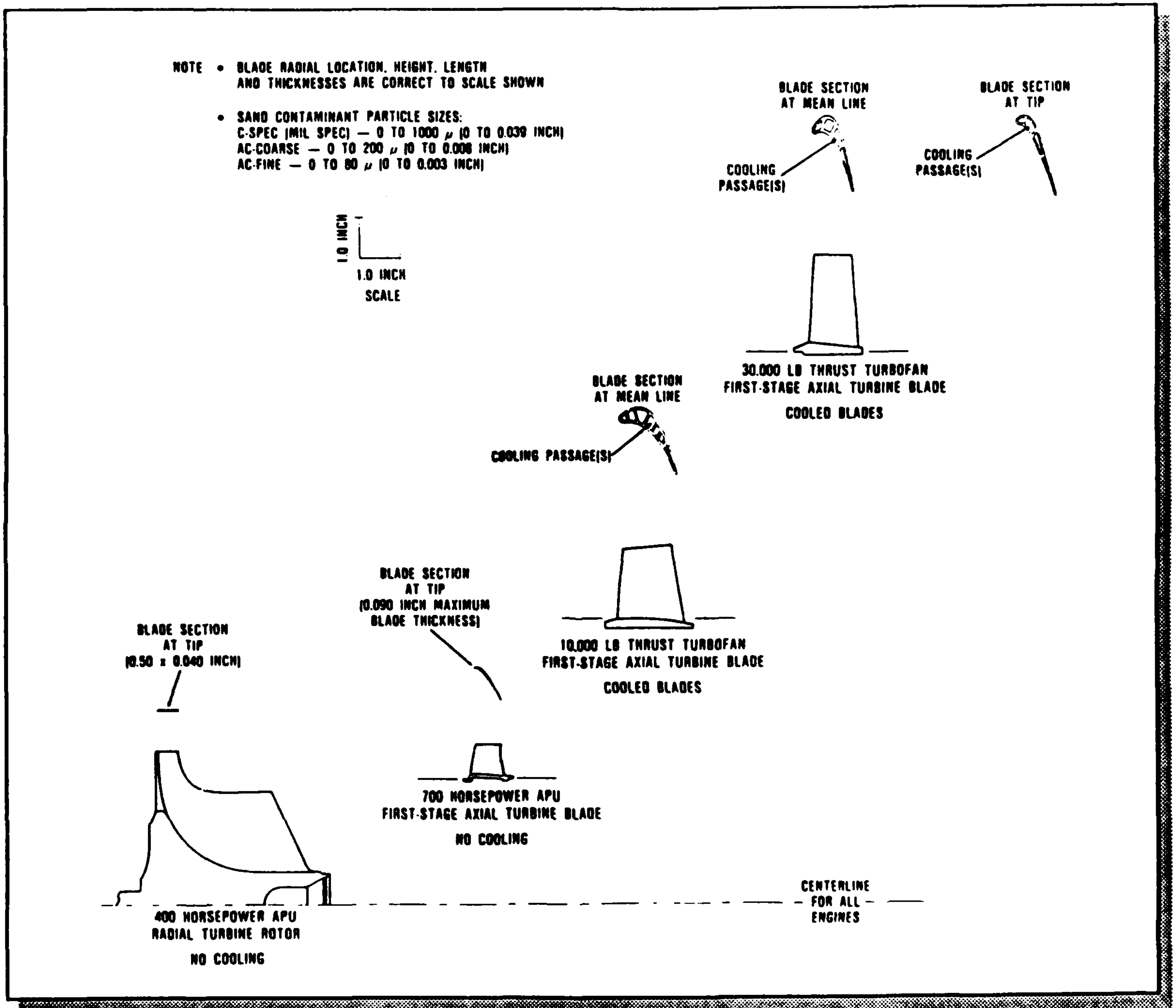


Figure 3-1 TECHNOLOGY SCALING APPLICATIONS

must be developed to allow the same cooling effects to be applied to the SPSs. Even if cooling passages could be fabricated they would be susceptible to becoming clogged by foreign objects.

Most components of the APU are similarly affected by size considerations. In addition, the physical size of the APU, up to 500 horsepower, limits the hot section turbine components to an uncooled configuration. When this uncooled APU is compared to a larger, cooled main aircraft engine, the time weighted percent of rated power that an APU must provide is much higher. In addition, the uncooled APU hot section parts operate at maximum power where the propulsion GTE operates over a wide range of power settings. The uncooled APU is then operating only slightly lower in TIT than the cooled propulsion GTE hot section parts on a time-weighted percent of rated power. The power distribution of the propulsion GTEs then allows for lower stress rupture time for an equivalent service life. These examples are used to clarify the point that APUs are unique small propulsion GTEs and cannot be classified with either turboshaft or turbofan engines, or cruise missile engines which have limited life requirements. It must be pointed out that the above operational requirements for APUs are true for virtually every SPS.

3.2 *TECHNOLOGY REQUIREMENTS*

3.2.1 <u>SPS Technology Development</u>

It appears that a very low priority for development efforts has been given to SPSs compared to the primary propulsion systems (propulsion GTEs) for the weapon systems. This is partially attributed to the fact that there is no centralized System Program Office (SPO) within the Air Force that concerns itself with this equipment. Without a government focal point to formally specify, monitor and manage the system SPS requirements, the prime weapon system contractor assumes the responsibility by default. SPS technology development has also suffered because of this situation. Without system acquisition agency sponsorship and support, the R&D community has been unable to justify the need for technology development funding. Several efforts are presently underway or planned to help upgrade the level of technology application in SPSs, but evidence of government agency coordination is lacking and the degree of need (i.e., weapon system requirements) is not thoroughly understood or documented.

Much of the turbomachinery technology used in the design of current power units is thus representative of the 1960's. There is a perceived technology application gap between small propulsion GTEs and SPSs. The trends in specific fuel consumption (SFC), turbine inlet temperature (TIT), and the available horsepower per

pound of airflow per second lag the trends for small propulsion GTEs. Some of this technology application gap may be attributable to the proprietary nature of the technology, but unique SPS requirements probably account for a larger percentage of the disparity.

3.2.2 SPS Technology Parameters

When discussing the technology requirements that are evolving for SPSs, it is important to use parameters that are not affected by the multitude of possible applications and component configurations. Several parameters have been developed which permit us to examine technology trends and to portray future technical goals in relation to historical trends. Parameters selected for this study include power density, specific power and specific fuel consumption. These three parameters are indicators of improved efficiencies and increases in power output based on relative size of the power system GTE.

As previously mentioned, secondary power systems were developed in the late 1950s. Initial development of the T-62 Titan was undertaken by Turbomach in 1957. This engine was initially developed as the primary propulsion unit for one-man helicopters for the US Navy. Although the requirements for this aircraft did not materialize, T-62 engine development continued aimed at airborne APU applications.

Some general SPS objectives for these technical parameters have been established by the Air Force. In the following paragraphs, these goals are presented in relation to the technical progress that has been achieved, or is projected to be achieved, from 1950 to 1990. The graphs are presented to depict trends rather than identify precise values.

Power Density: This parameter is defined as the horsepower generated per cubic foot of volume. In Figure 3-2, power density is plotted against core gas generator airflow in pounds of air per second. The power density numbers for typical SPS equipments range from 100 for 1950 vintage products to a projection of 250 for 1990. Current power system GTE applications have average power density values of about 200. The Air Force goal of 400, nearly double the 1990 projection, for the year 2000 seems very ambitious without some type of technological "break through."

Specific Power: Specific power is defined as the horsepower produced divided by the inlet air flow in pounds of air per second. The specific power ratings for typical SPS applications exhibited the trends depicted in Figure 3-3 for the 1950 to 1990 time period. Current values for specific power average about

100. The Air Force goal appears to be in excess of a 30 percent improvement for this parameter.

Specific Fuel Consumption: For power applications, this parameter is defined as the fuel flow in pounds per hour divided by the horsepower being produced. In other words, this is the amount of fuel required to produce one horsepower. Figure 3-4 depicts the general range for this parameter for the 1950 to 1990 time frame. Current values for specific fuel consumption average 0.8. Here again the Air Force goal of 0.5 represents an approximate 20 percent improvement over the figures projected for 1990.

The technological ramifications of these goals impact every SPS component. Dramatic advances in turbomachinery, thermodynamics, aerodynamics, power conversion and system integration must be made to achieve these AF goals. Table 3-2 identifies the SPS technology needs which will have to be considered on future SPS development efforts.

TABLE 3-2

SPS TECHNOLOGY NEEDS
• Advanced cycles (regenerative, higher temperatures and pressure ratios)
• Advanced components (seals, bearings, combustors, compressors, turbines and gears)
• Advanced materials (ceramics, carbon-carbon and powder metals)
• System design (integrated functions, structure and packaging)

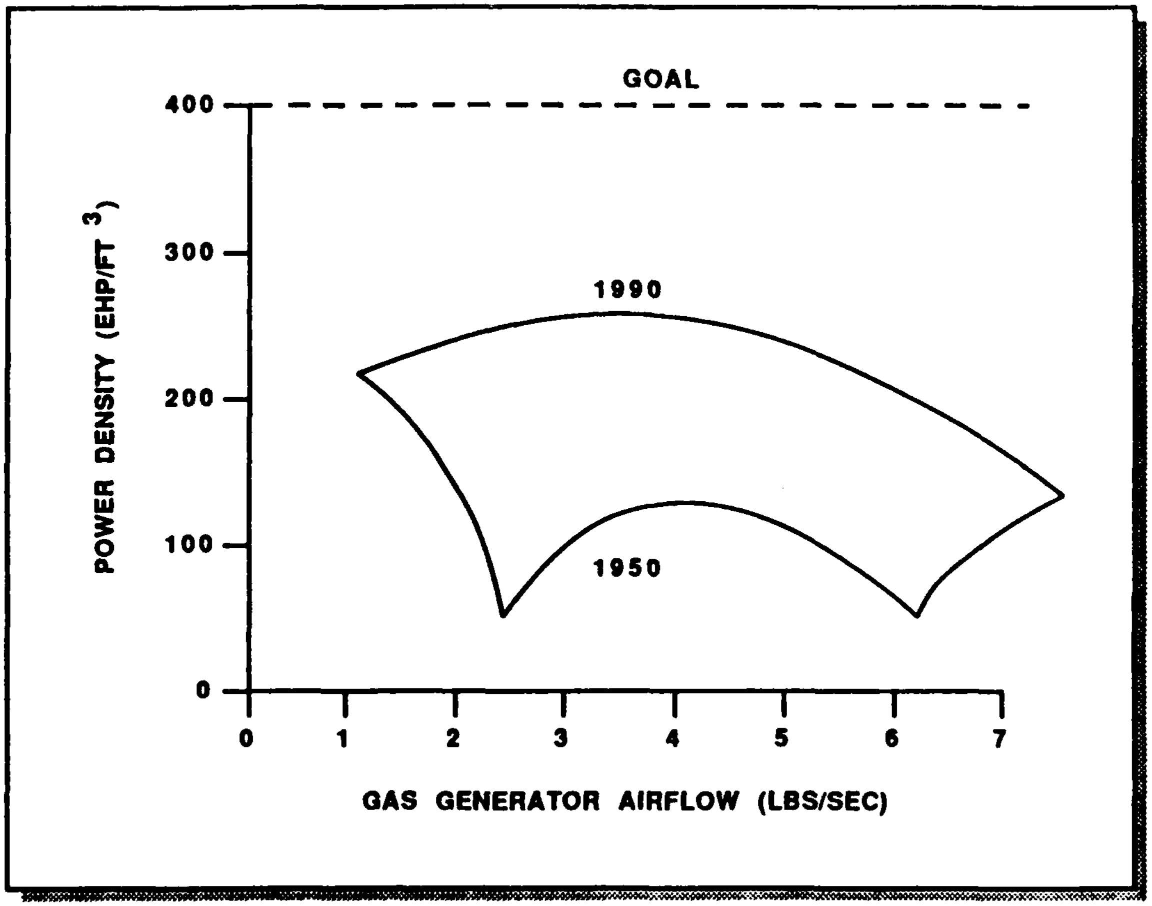


Figure 3-2 SPS POWER DENSITY

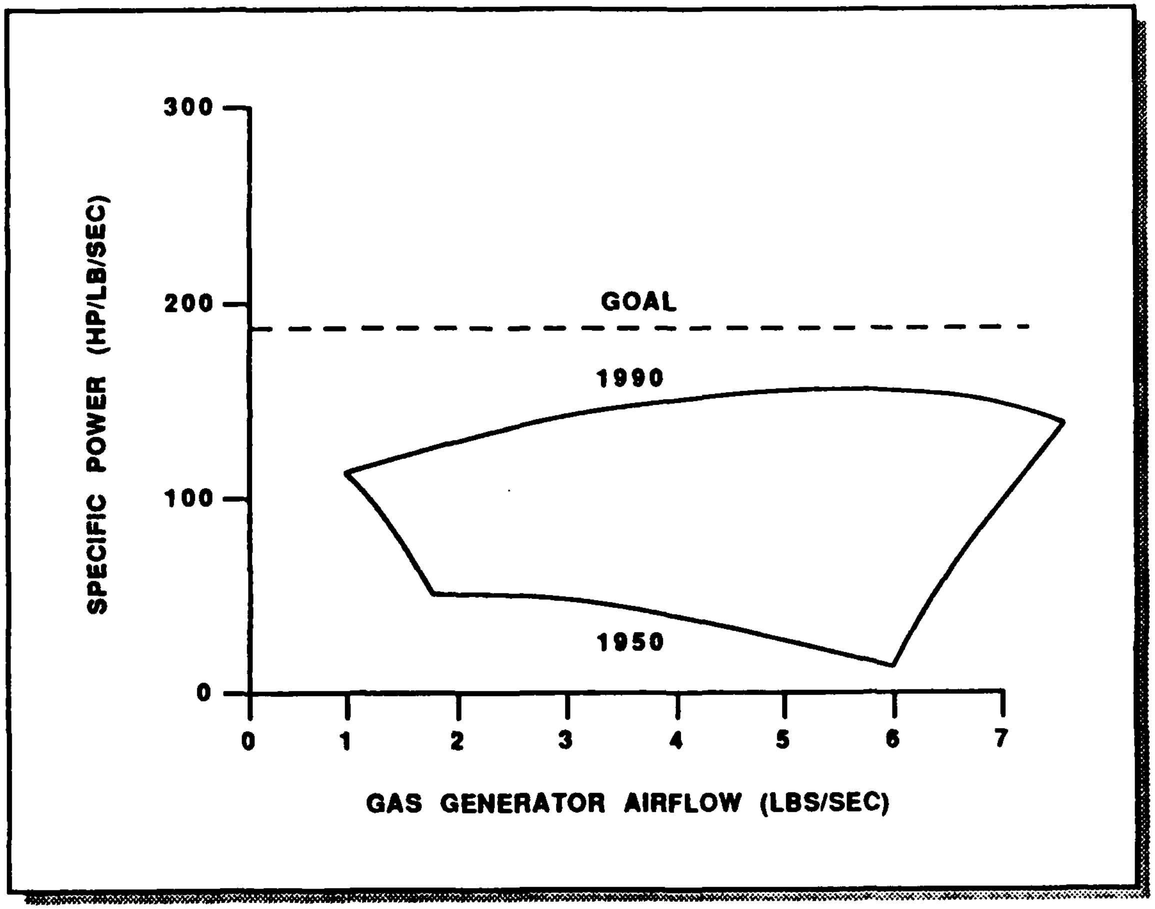


Figure 3-3 SPS SPECIFIC POWER

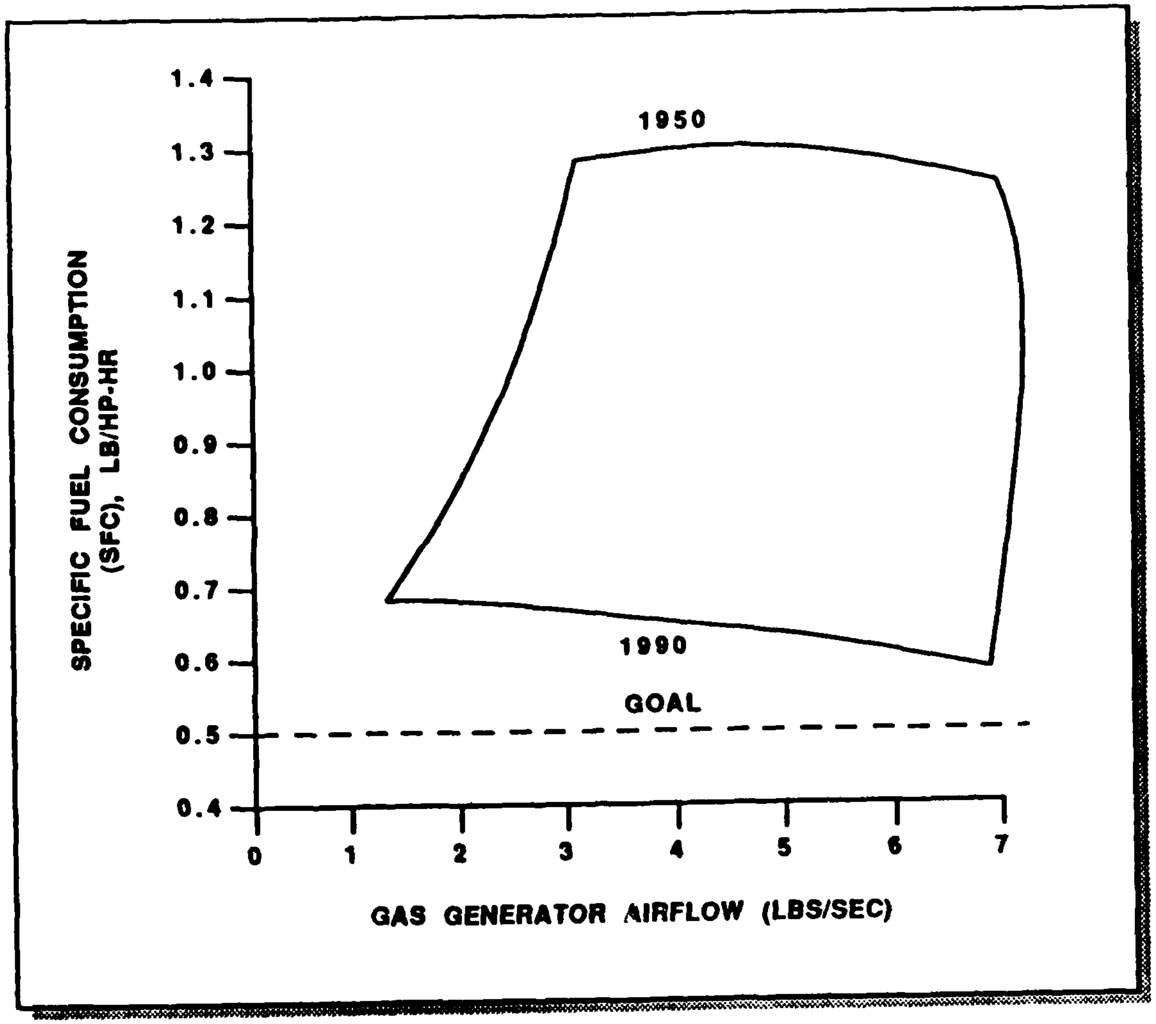


Figure 3-4 SPS SPECIFIC FUEL CONSUMPTION

3.3 TECHNOLOGY EFFORTS

On the surface, there appears to be a great deal of DOD sponsored R&D effort applicable to SPSs. As previously discussed, however, very little sponsored R&D has been accomplished which is uniquely directed at SPS improvement. The applicability of GTE R&D is also limited because of size effects, proprietary data problems and other issues. In short, the work that has been accomplished is product improvement as opposed to applied research.

Based upon the limited nature of this study, Table 3-3 was developed to show the dramatic disparity which exists between

TABLE 3-3

TECHNOLOGY FUNDING SOURCES

TECHNOLOGY ACTIVITY/ FUNDING SOURCE	PROPULSION GTE	SPS
R&D FUNDING		
Analysis/Design Methods	C	OO
Materials/Processes	C	OO
Component Technology	C	OO
Core Gas Generator	C	OO
Configuration Technology	C	N
Technology Demonstration	AR	OO
SYSTEM FUNDING		
Full Scale Development	AR	AR
Component Improvement	C	LF
MANUFACTURING FUNDING		
Repair Technology	AR	N
Manufacturing Technology	C	OO

KEY

C - Continuing Activity/Funding
AR - Performed for a specific system application as required
OO - Specific activity funded on occasion
N - Non-Funded
LF - Limited Funding

funding sources for propulsion GTEs and SPSs. Exceptions to the presented scenarios could probably be cited for each funding category, but the previously presented financial data reflects the same conclusion.

Isolated examples of non-DOD funded SPS technology development programs were identified during the course of this study. Synopses of these efforts are provided below.

- The Department of Energy (DOE) initiated a program in October 1979 to improve the performance of small gas turbine engines for use in passenger cars. The two contractor teams selected to accomplish this task were 1) Garrett Turbine Engine Company/Ford Motor Company, and 2) Allison/Pontiac Division of General Motors. The primary objective of these programs was to utilize ceramics in small gas turbines to improve the performance by increasing turbine inlet temperatures. The ceramic turbine elements do not require cooling thereby eliminating the penalty associated with cooling. The goal of these programs was to have each team conduct an endurance test on an engine for 100 hours at a turbine inlet temperature of 2350-2500 degrees F. The gas turbines are in the 100 horsepower class, use a regenerative cycle, have a mass flow of .80 pounds/second and pressure ratios of 4 1/2 to 5 to 1.

- Army activities include an ongoing program to develop a small gas turbine in the 50-100 horsepower class. The engine is to be designed for multiple applications and is to have a maximum specific fuel consumption of 0.75 or better at 50 horsepower.

- NASA planned to spend several million dollars per year on the Advanced Small Engine Technology (ASET) starting in FY87.

- The Air Force Aero Propulsion Laboratory is seeking support and funding for a program called "Technology for Gearless Aircraft Power Systems" or T-GAPS. Fundamentally, this initiative would eliminate gearboxes and the hydraulic distribution system by substituting integral generators in the propulsion GTE and SPS units and would utilize electro-hydrostatic or electromechanical actuators in lieu of conventional hydraulic distribution systems.

4.0 STUDY FINDINGS

4.1 FINDINGS

4.1.1 SPS Producers

- US SPS production is currently accomplished by two Primes.
- Ninety percent of military SPS shipments ($s) are produced by these two Primes.
- US SPS producers satisfy the majority of the world market for airborne and stationary applications.

4.1.2 SPS Manufacturing Concerns

- Single source SPS suppliers are common to propulsion GTE suppliers of critical parts.
- Critical SPS occupations require training times in excess of 12 months.
- Foreign source dependencies exist for specialized manufacturing equipment.
- SPS production is dependent upon availability of several strategic and critical materials for high temperature alloys for hot section components.

4.1.3 Operational Requirements

- Airborne SPS equipment, with the APU being the core of the entire system, is unique due to its operation, size and duty cycle.
- The duty cycles imposed on APUs are more severe than those imposed on the main engine consisting of severe mechanical and thermal transients, efficient operation over a wide speed range, high mission operation mix, with high reliability and ease of maintenance.
- Modern day aircraft have operational requirements which have increased greatly over past aircraft needs.

4.1.4 Technology Perspective

- The propulsion GTE life cycle activities are undergirded by a continuum of technological activity that is both well funded and managed by the DOD.

- The Air Force technology goals established for SPSs for the year 2000 are extremely ambitious in comparison to historic trends.

- The physical size of APU components required for modern-day and future tactical aircraft have imposed limits on technology transfer from large propulsion GTEs.

- SPS requirements are typically not defined until late in the FSD phase of the acquisition cycle. This late consideration usually results in the SPS being limited to state-of-the-art technology.

- Historically, secondary power systems and components have received intermittent, selective government support and have made much less technological progress than propulsion GTEs. The progress that has been made falls into the category of required system engineering development rather than pre-planned, incremental, technical development.

4.2 GENERAL CONCLUSIONS

- Without major technological breakthroughs future SPSs will continue to suffer performance shortfalls.

- Future demands of the SPS require designs which are smaller, lighter and more powerful than today's units. In addition, market pressures dictate lower costs and higher reliability and maintainability. These factors combine to suggest the need for significant advances in materials and manufacturing processes to be used in SPSs; advances in such areas as materials and processes which have not been perfected for use in production.

- Increased demands can no longer be satisfied by increases in component efficiency and capability. Integrated designs must be developed, and demonstrated to achieve projected goals.

- Fragmented, multi-agency SPS development activities will not meet projected requirements. Through well-conceived, broadly based, well-funded and inter-agency-managed technology program will the projected military SPS weapon system requirements be met.

4.3 RECOMMENDATIONS

- Identify and document the specific SPS manufacturing technologies which must be available to meet the projected weapon system operational requirements.

- Conduct a detailed review of the SPS supplier base to identify specific technology, capacity and capability constraints to future weapon system acquisitions.

4.4 ACTION PLANS

4.4.1 SPS Manufacturing Technology Requirements

Priority: 1

Finding(s): With currently identified Air Force operational requirement goals there is a need to assess the capability of the manufacturing base to both produce and repair these power system GTEs. There are some major "breakthroughs" needed to achieve these operational goals, the manufacturing capability must be available in the same timeframe to support these needs.

Recommended Action: Based on the operational goals established for power system GTEs, an effort must be undertaken to determine the ability of industry to meet these needs. A study should be made of those technologies which are required to meet these goals and determine whether capability is present or will be available when needed to both produce and repair these SPSs.

Basis:

a. Analysis Process: By comparing the Air Force goals for secondary power systems with current day performance parameters it was determined that significant progress would not be possible, based on historical trends, without some major technological "breakthroughs."

b. End Items(s) Affected: The report indicates that secondary power systems are increasing in applications and all weapon systems require some type of auxillary power source. Additionally, ground power systems will require this same technology as increased reliability and maintainability parameters are defined for these systems.

OPR: AFWAL/MLT

Cost Estimate or Manpower Requirements:

a. Types of Funds: $2.5M, PE78011F

b. Source of Funds (Primary): MANTECH, PDP J212

c. When are Funds Needed? FY89 - $1.5M, FY90 - $1.0M

d. Type of Manpower (Government or Contractor): Contractor

e. Basis for Cost Comparison: The cost estimate is a ROM based on a comnparison of this effort with existing MANTECH projects of similar scope.

Impact Statement

a. Window of Opportunity: FY89.

b. Expected Benefits: The Air Force will realize increased operational performance from secondary power systems if adequate manufacturing technology is available to produce those systems needed for future weapon systems in the 1990-2000 timeframe.

c. How and when to measure benefits: Benefits will be measured in the operational inventory when secondary power systems achieve those operational goals established for the weapon system.

4.4.2 SPS Subcontractor Study

Priority: 2

Finding(s): There are currently two major producers of secondary power systems who invaribly purchase materials and components from the same suppliers and vendors. Additionally, since power system GTEs utilize similar technology to propulsion GTEs, it is assumed that the same vendors and suppliers identified in the Gas Turbine Engine (GTE) Production Base Analysis (PBA) Study will be providing components and materials to the secondary power system Primes.

Recommended Action: Identify suppliers and vendors who are providing critical components and materials for the secondary power system Primes. As a minimum, these critical components will be defined as foreign sourced, single sourced, sole sourced,

technology critical, proprietary, leadtime in excess of 15 months, and unit costs greater then $1,000. Document these suppliers and vendors and compare with the suppliers and vendors identified for the GTE PBA Study.

Basis:

a. Analysis Process: The contractors were asked to identify critical suppliers, regardless of above mentioned criteria, and those names that were mentioned were the same ones identified in the GTE PBA Study as critical subcontractors.

b. End Items(s) Affected: All weapon systems utilizing power system SPSs.

OPR: AFSC/ASD

Cost Estimate or Manpower Requirements:

a. Types of Funds: PE78011F, $100,000.

b. Source of Funds (Primary): Planning, PDP J628

c. When are Funds Needed? FY89

d. Type of Manpower (Government or Contractor): Government.

e. Basis for Cost Estimate: The above is an estimate based on past experience and the actual costs of previous studies of this nature.

Impact Statement:

a. Window of Opportunity: FY89 and continuing.

b. Expected Benefits: This will provide data to be input into the Roadmap Prototype Data Base. Analysis can be performed to determine the critical subcontractors to the GTE industrial sector.

c. How and when to measure benefits: Upon completion of the study.

APPENDIX A

Secondary Power Questionnaire

1. Name and address of your firm or corporate division.

____

____

____

2. If your firm is wholly or partly owned by another firm, indicate the name and address of the parent firm and extent of ownership. ____

____

____

3. Identify the location of your secondary power unit (SPU) parts manufacturing establishment(s) in the United States and enter the value of <u>total</u> (i.e.,establishment shipments) defense and non-defense shipments in 1986. (See definition of SPU parts and shipments).

				Value of 1986 shipments	
	Locality	State	Zip Code	Defense	Non-Defense
(a)	________	___	______	______	______
(b)	________	___	______	______	______
(c)	________	___	______	______	______

6. GOVERNMENT SPONSORED MODERNIZATION PROGRAMS: (i.e. IMIP, TECH MOD, MANTECH, REPTECH - see definitions)

A. Are you currently involved in a Government sponsored modernization program with respect to your SPU parts manufacturing operations? yes ____, no ____

If yes, please identify:______________________________

____

____

____

B. How beneficial do you feel Government sponsored modernization programs are?______________________________

____

____

C. Which programs could help your firm?____________________

____

____

Will they result in reduced lead times? ________

Will they lower production costs? ________

Will they lower SPU part prices to DOD? ________

Will they help you compete on the world market? ________

D. What problems still exist that these programs do not address?

____

____

____

7. SUPPLIERS:

Do you have any SOLE source or SINGLE source suppliers for manufacturing equipment, parts/components, processes or materials (see definitions of sole and single source)? Yes____, No____

If yes, please identify source and item.

____

____

____

8. MATERIALS USAGE:

Indicate which of the strategic/critical materials listed below is used in the production of defense SPU parts you supplied in 1986.

____Aluminum	____Antimony	____Asbestos	____Beryllium
____Chromium	____Cobalt	____Columbium	____Fluorspar
____Gallium	____Manganese	____Platinum Grp.	____Tantalum
____Tin	____Titanium	____Tungsten	____Vanadium
____Zirconium	____Silicon (high purity)	____Nickel	____Rhenium

____Pan Based Fibers ____Pitch Based Fibers ___Other (specify)

9. CRITICAL OCCUPATIONS:

List below. (See definition of Critical Occupations)

Job Title	Number Employed	Training Period (in months)

10. EMPLOYMENT:

Enter the number of employees from 1984 through 1986 as requested below. (See definitions of Scientists and Engineers, and Production Workers).

	1984	1985	1986
Scientists and Engineers	________	________	________
Production Workers	________	________	________
Administration	________	________	________
Total	________	________	________

11a. TECHNOLOGY:

a. CAD
b. CAM
c. Robotics
d. CNC Machinery
e. Bar Coding
f. Hard Automation
g. Laser Cutting/ Welding
h. Integrated CAD/CAM
i. Automated Materials Handling
j. Flexible Manufac- turing
k. Computer-Based Test Controls
l. Quality Assurance Mgmt Info System
m. Work Center Technology
n. Vision-Oriented Systems
o. Composites
p. Powder Metallurgy
q. Other (specify)

From the letter coded list above, identify technologies you currently utilize.______________________________

11b. PRODUCTIVITY:

On the table below, rank the top three activity areas from one (the largest productivity increase) to three (the third largest productivity increase) where the application of new technologies from those listed above could most effectively increase productivity. In the right column, enter the letter codes of the technologies listed above.

ACTIVITY AREA	RANK	NEW TECHNOLOGIES TO INCREASE PRODUCTIVITY
Fabrication	____	____________________
Assembly	____	____________________
Inspection	____	____________________
Testing	____	____________________
Auxiliary	____	____________________
Inventory	____	____________________
Materials	____	____________________

12. FOREIGN SOURCES:

Are any critical parts or materials you use to make SPS parts shipped from overseas? Yes___, No___

If yes, please identify how shipped. (from foreign source to your plant)

____

____

13. FOREIGN ESTABLISHMENTS:

Enter the location and primary activity of any establishment outside the United States that your firm wholly or partly owns or controls or is affiliated with or has license agreements with, tha manufactures SPU parts.

NAME	COUNTRY	PRIMARY ACTIVITY

14. FOREIGN INTEGRATION:

If any of the foreign establishments you listed above are integrated with your U.S. operations on a normal basis, please specify the nature of that integration in the space provided below.

15. ESTABLISH NEW SOURCE:

If the foreign establishments that you interact with suddenly ceased operations for an idefinite period, what adjustments would you need to make in your U.S. operations to counteract this interruption, how long would it take to establish a

new source, and how would the interruption effect your surge and mobilization capabilites?

____
____
____
____
____

16. OFFSET AGREEMENTS:

In recent years, have offset agreements affected your firm? (See definition of offset agreement) Yes____, No____

If yes, how (cite examples)?________________________________
____
____
____
____
____

17. REASONS - FOREIGN SOURCES:

Complete the following table addressing which foreign made critical manufacturing equipment, parts, components, or materials you use in your manufacturing operations. Use the following coded reasons why a foreign source is used in completing the table:

a. No known domestic source
b. Domestic source not available or inadequate
c. Offset agreement
d. Lower cost
e. Quicker delivery

f. Better quality

g. other (specify)

Item	Country of Origin	For equipment Are spare parts/maintenance available only from a foreign source?	Reason why foreign source

18. CONTINGENCY PLAN:

If the foreign sourced items identified in question 5 are lost, what is your contingency plan (i.e. qualified domestic source, alternate material) and does this impact your ability to surge or mobilize?

19. SPU TECHNOLOGY DEVELOPMENT REQUIREMENTS

Rank SPU technology development initiatives, by SPU component or function combination (i.e., combining start and APU capabilities in one unit), for the elements listed below. Please rank 1 thru 5, with 1 being the highest rank.

	Fighter	Cargo
(a) Compressor	________	________
(b) Combustor	________	________
(c) Turbine	________	________
(d) Power Transfer	________	________
(e) System Combination	________	________

20. OTHER COMMENTS ON AF PROCUREMENT POLICY

(a) Dual Sourcing: ______________________________

(b) Acquisition Policy: ______________________________

(c) Specifications and Standards: ______________________________

(d) Testing Requirements: ______________________________

(e) Research & Development: ______________________________

(f) Other: ______________________________

APPENDIX B

LARGE INDUSTRIAL ENGINES - XIII

AEG-Kanis Turbinenfabrik GmbH
Gas Turbine Div.
Altendorfer Strasse 39-85
D-4300 Essen
West Germany

Engine: Frame 5

Alsthom-Atlantique
Gas Turbine Div.
3, ave. des Trois Chenes
Belfort
90001 France

Engine: Frame 5

ASEA Stal AB
S-612 20 Finspong
Sweden

Engine: GT120, GT200

BBC Brown Boveri, Inc.
Power Generation Div.
1460 Livingston Ave.
North Brunswick, NJ 08902

Engine: Type 8/9/11/13/13E

Fiat Aviazione SpA
Via Nizza 312
Torino
10127 Italy

Engine: LM2500

Fiat TTG SpA
Via Cueno 20
Torino
10152 Italy

Engines: TG16, TG20

General Electric Co.
Marine & Industrial Engines & Service Div.
1 Neumann Way
Cincinnati, OH 45215-6301

Engine: LM2500, LM5000

General Electric Co.
Gas Turbine Div.
1 River Road
Schenectady, NY 12345

Engine: Frame 5

Kawasaki Heavy Industries Ltd.
Jet Engine Div.
1-1 Kawasaki-cho
Akashi
Hyogo Pref., 673'
Japan

Engine: Olympus

Kvaerner Brug A/S
Steam and Gas Turbine Div.
Kvaernerveien 10
Oslo 1
Norway

Engine: Frame 5

Mitsubishi Heavy Industries
Power Systems Headquarters
2-5-1 Marunouchi
Chiyoda-ku
Tokyo 100
Japan

Engine: MW-252

Nuovo Pignone
Via Felice Matteucci 2
50127 Firenze
Italy

Engines: Frame 5, Frame 6, Frame 9

Rolls-Royce Ltd.
Industrial & Marine Div.
P.O. Box 72
Ansty
Coventry
United Kingdom

Engines: RB211, Olympus

Sulzer-Escher Wyss Ltd.
Thermal Turbomachinery
P.O. Box 8023
Zurich
Switzerland

Engine: Type 10

Westinghouse Canada, Inc.
Turbine & Cenerator Div.
P.O. Box 510
286 Sanford Avd., North
Hamilton, Ontario Canada L8N 3K2

Engines: CW251, CW382

MEDIUM INDUSTRIAL ENGINES - XIV

AEG-Kanis Turbinenfabrik GmbH
Gas Turbine Div.
Altendorfer Strasse 39-85
D-4300 Essen 1
West Germany

Engine: Frame 3

ASEA Stal AB
S-612 20 Finspong
Sweden

Engine: GT35 Solar Mars, under agreement

Dresser Industries, Inc.
Dresser Clark Div.
P.O. Box 560
Olean, NY 14760

Engine: DC-990

Fiat Aviazione SpA
Marine & Industrial Products Div.
via Nizza 312
Turin
Italy I-00187

Engine: LM500

General Electric Co.
Marine & Industrial Engines & Service Div.
1 Neumann Way
Cincinnati, OH 45215-6301

Engines: LM500, Frame 3

General Motors
Allison Gas Turbine Division
P.O. Box 420
Indianapolis, IN 46206

Engines: 501-KC, 501-KB, 501-KB5, 570-KC, 570-KA, 571-KC, 571-KB

Hispano Suiza
Gas Turbine Div.
Rue du Capitaine Guynemer
92270 Bois-Colombes
France

Engines: THM 1304, THM 1304R

Kawasaki Heavy Industries Ltd.
Industrial Gas Turbine Div.
1-1 Kawasaki-cho
Akashi
Hyogo Pref.
673
Japan

Engine: Spey

A/S Kongsberg Vapenfabrikk
Gas Turbines and Power Systems Div.
N-3601 Kongsberg
Norway

Engines: KG3, KG5

Kvaerner Brug A/S
Steam and Gas Turbine Div.
Kvaernerveien 10
Oslo
Norway

Engine: Frame 3

Mitsubishi Heavy Industries
Power Systems Headquarters
2-5-1 Chiyoda-ku
Tokyo 105
Japan

Engine: MF-111

Mitsui Engineering & Shipbuilding Co., Ltd.
Energy Engineering Div.
5 Chome 6-4 Tsukji
Chou-ku
Tokyo 104
Japan

Engines: SB30, SB60, SB90

North American Turbine Corp.
Industrial Products Div.
P.O. Box 40510
Houston, TX 77240

Nuovo Pignone
Via Felice Matteucci 2
50127 Firenze
Italy
Engines: Frame 1, Frame 3

Rolls-Royce Ltd.
Industrial & Marine Div.
P.O. Box 72
Ansty, Coventry CV7 9JR
United Kingdom

Engines: Avon, Spey

Ruston Gas Turbines Ltd.
P.O. Box 1
Lincoln LN2 5DJ
England

Engines: TB5000, Tornado

Solar Turbines, Inc.
P.O. Box 85376
San Diego, CA 92138-5376

Engines: Mars (GSC-12,000, GSE-12,000, MD-12,000)

Sulzer-Escher Wyss Ltd.
Thermal Machinery
P.O. Box 8023
Zurich
Switzerland

Engines: Type 3, Type R3, Type 7, Type R7

Westinghouse Canada Inc.
Turbine & Generator Div.
P.O. Box 510
Hamilton
Ontario, Canada L8N 3K2

Engines: CW182

SMALL INDUSTRIAL ENGINES - XV

Avco Corp.
Avco Lycoming Stratford Div.
550 S. Main St.
Stratford, CT 06497

Engines: TF25, TC35, TF35, TF40

Bet Shemesh Engines Ltd.
Mobile Post Haela 99000
Bet Shemesh
Israel

Engines: M2Tl, M5Tl

Allied-Signal Aerospace Company
Garrett Auxiliary Power Division
2739 E. Washington Street
P.O. Box 5227
Phoenix, AZ 85010

Engine: 1M831

Kawasaki Heavy Ind. Ltd.
Jet Engine Div.
1-1 Kawasaki-cho
Akashi
Hyogo Pref.
673 japan

Engines: M1A, M1T, S2A

A/S Kongsberg Vapenfabrikk
]Gas Turbines and Power Systems Div.
P.O. Box 25
N-3601 Kongsberg
Norway

Engines: KG2, KG3

Ruston Gas Turbines Ltd.
P.O. Box 1
Lincoln England

Engine: TA1750, TA2500

Solar Turbines, Inc.
P.O. Box 85376
San Diego, CA 92138-5376

Engines: Centaur, Saturn

Turbomeca SA
Bordes
Bizanos
France F-64320

Engines: Bastan, Bi-Bastan, Turmo

Fiat Aviazione SpA
Marine & Industrial Products Div.
Via Nizza 312
Turin
Italy I-00187

Engine: FA 150 Argo

Allied-Signal Aerospace Company
Garrett Auxiliary Power Division
2739 E. Washington Street
P.O. Box 5227
Phoenix, AZ 85010

Engines: Model 30, 36, 85, 95, 105, 165, 331, 660, 700

KHD Luftfahrttechnik GmbH
Hohemarkstrasse 60-70
6370 Oberursel
West Germany D-6370

Engine: T312

Lucas Aerospace
Engine Systems Div.
Shaftmoor Lane
Birmingham, West Midlands
United Kingdom B28 8SW

Engines: MK 2, MK 4

Microturbo SA
BP 2089
Chemin du Pont de Rupe
Toulouse
France F-31019

Engines: Gevaudan, Dragan, Noelle, Saphir

United Technologies
Pratt & Whitney Aircraft Canada
Box 10
10000 Marie-Victorin Blvd. East
Longueuil PQ J4K 4X9
Canada

Engines: ST6

Turbomach
220 Pacific Highway
P.O. Box 85376
San Diego, CA 92138-5376

Engines: Gemini, Titan

Turbomeca SA
Industrial Gas Turbines Dept.
Bordes 64320
Bizanos Bordes
France F-64320

Engines: AST600, AST950

Williams International
Box 200
2280 W. Maple Rd.
Walled Lake, MI 48088

Engines: WR9, WR27